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| (54) Title: GENETIC TRANSFORMATION METHOD  |  |  |  |
| (57) Abstract<br><p>A method of introducing a nucleic acid into a plant cell comprises providing a culture of plant cells, placing proximate the plant cell culture a multiplicity of elongate needle-like bodies, such as silicon carbide whiskers and silicon nitride whiskers, and subjecting the said cell and bodies to physical motion so as to create relative movement, and thereby collisions, between the bodies and the cells whereby, on collision of a body and a cell, the cell is breached providing means for ingress of nucleic acid to the cell. The method is particularly applicable to cell culture types from which whole plants may be regenerated and its intended use is for the genetic transformation of cereal crops such as corn <i>Zea mays</i>.</p>                 |  |  |  |

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#### GENETIC TRANSFORMATION METHOD

This invention relates to the introduction of DNA into cells, particularly plant cells in order to effect transformation thereof by the inserted DNA.

In order that a cell may be efficiently transformed,

- 5 certain requirements must be satisfied. First the gene to be inserted must be assembled within a construct which contains effective regulatory elements which will drive transcription of the gene. Next, there must be available a method of transporting the construct into the cell. Once the construct
- 10 is within the cell membrane, integration into the endogenous chromosomal material either will or will not occur. The probability of integration may be improved by certain means but, in general, integration is simply a matter of uncontrolled chance. Finally, as far as plants are concerned the target
- 15 cell type must be such that cells can be regenerated into whole plants.

This invention is concerned with the second of these requirements, the transport of the gene construct through the cell wall. The first requirement is a matter for the skills of

- 20 molecular engineering and the question of regenerability is a problem for the cell biologists and experts in tissue culture.

Plant cells are more difficult to transform than bacterial or animal cells because the presence of hard cell walls presents a barrier to insertion of the construct through that

- 25 wall. However, many dicotyledonous plant species can be transformed using the natural gene transfer ability of Agrobacterium tumefaciens or Agrobacterium rhizogenes. Monocotyledonous plants, to which class the most agriculturally important cereals belong, remained for a long time recalcitrant
- 30 to transformation on two counts. Firstly, such species are not

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within the host range of Agrobacterium and secondly regenerable cell types have been difficult to find. However, recent work has given methodology for the creation and maintenance of regenerable maize callus and cell suspension cultures: see

- 5 Armstrong C.L. and Green C.E.; *Planta* Vol. 164, pages 207-214 (1985) "Establishment and maintenance of friable embryogenic maize callus and the involvement of L-proline"; and, Kamo K.K. and Hodges T.K.; *Plant Science* Vol.45, pages 111-117 (1986) "Establishment and characterization of long-term embryogenic
- 10 maize callus and cell suspension cultures"

In "Gene Transfer to Cereals: An Assessment"; Potrykus, *Biotechnology* 8, 535-542, June 1990, there is an assessment of all the then known methods of transforming cereals. The problems associated with the various methods are summarised in

15 that paper.

Thus the choice of method for the transformation of plant cells tends to be limited to those which are convenient for the target plant type. As a generalisation, dicotyledonous plants are relatively easy to transform whereas monocotyledonous

20 plants are very difficult, there being only a few techniques available in respect of which success has been reported, and that with very low success rate. There is, therefore, a need to make available new techniques for transformation of monocotyledonous plants.

25 One method which is claimed to transform cereal plant cells is the procedure known as "microinjection" where, under the microscope, a DNA construct is injected from a hollow needle into a target cell. A variant of that procedure is the rupturing of the cell wall with a needle, the DNA being added

30 to the surrounding medium and allowed to diffuse into the cell through the break in the cell wall. This variant is known as "micropricking". Both of these procedures require a high degree of manipulative skill by the operator and are very time consuming.

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It is probably true to say that to date the most effective methodology for the introduction of gene constructs into monocotyledonous cells has been the so-called "biolistics" method in which high density metallic particles, usually of 5 tungsten or gold, are coated with the gene construct and are propelled by an explosive release of gas at a target cell culture. This alternative approach abandons the high precision of targeting which is inherent in microinjection and 10 micropricking, in favour of a rapid "pepperpot" approach which enables large numbers of cells to be "hit" in a short time, giving a large number of putative transformants for screening.

Effective though the biolistic method may be, it requires expensive hardware and, although rapid by comparison with some other methods which have been attempted, is time-consuming. It 15 does, however, achieve high numbers of insertions at each bombardment. One problem with this technique is the effect of the blast of expanding gas on the target tissue. Another is the difficulty of aiming the projectile shower at a selected area of the target.

20 Mixing of plant cells with plasmid DNA a sub-micron diameter fibres or whiskers is a simple and inexpensive alternative transformation method. There have been two published reports of corn transformation using silicon carbide whiskers. The first described transient GUS expression in Black 25 Mexican Sweet (BMS) corn suspension cells (Kaeppeler et al., 1990). The same group have recently published their results on stable transformation of BMS and tobacco (Kaeppeler et al., 1992). In the corn system a mean of 3.4 BASTA-resistant BMS colonies were recovered from each vortex-treated sample of 30 cells (300µl packed cell volume) using a BAR and GUS-containing plasmid. Sixty five per cent of these herbicide-resistant colonies expressed GUS. (Kaeppeler H.F., Gu W., Somers D.A., Rines H.W., Cockburn A.F. (1990) "Silicon carbide fiber-mediated DNA delivery into plant cells", Plant Cell Reports 9: 415-418,

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and, Kaeppeler H.F., Somers D.A., Rines H.W., Cockburn A.F. (1992), "Silicon carbide fiber-mediated stable transformation of plant cells", Theor. Appl. Genet. 84: 560-566

5 An object of the present invention is to provide an efficient and rapid method for the introduction of nucleic acids into plant cells.

According to the present invention there is provided a method of introducing a nucleic acid into monocotyledonous plant cells, comprising providing a culture of plant cells, 10 placing proximate the plant cell culture a multiplicity of elongate needle-like bodies and subjecting the said cell and bodies to physical motion so as to create relative movement, and thereby collisions, between the bodies and the cells whereby, on collision of a body and a cell, the cell wall is 15 breached providing means for ingress of nucleic acid to the cell.

Preferably the needle-like bodies are selected from the group consisting of silicon carbide whiskers and silicon nitride whiskers.

20 It may be preferred to pre-mix the needle-like bodies and nucleic acid and thereafter add the pre-mix to the cell culture.

When whole plants are required it is preferred that the said cell culture is of plant cells capable of regeneration 25 into whole plants.

The invention is particularly applicable to a suspension culture of regenerable cells of Zea mays.

30 The physical motion applied to the cells, bodies and nucleic acid may be rotational, reciprocating or oscillating motion.

Preferably the nucleic acid is a DNA capable of genetically transforming the said cell.

In practice, the needle-like bodies and DNA are mixed and then added to the cells and the mixture agitated. However, it

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makes little difference the order of addition and agitation is used. One embodiment of the invention comprises mixing the DNA and needle-like bodies (hereafter referred to simply as "fibres) then adding this mixture to the cell suspension. The final  
5 mixture is vortexed together. The cells can then be incubated, and tested for expression of recombinant DNA. It has been found that the efficiency of DNA delivery varies according to the conditions; it is affected by several factors including the following: vortex time; cell suspension type (variation also  
10 found by H F Kaepler et al, 1990, Plant Cell Reports, 9, 415-418); cell suspension age; osmolarity of culture medium; type of fibres; number of fibres present; type of DNA construct; concentration of DNA. Other factors which may affect DNA delivery include: the physical mixing methods used;  
15 the size, shape and uniformity of the fibres; the topology of the DNA (eg. linear, supercoiled); the presence of "carrier" DNA alongside the transforming DNA.

Many fine fibrous materials are known which may be used as the needle-like bodies in this invention, for example alumina,  
20 silica, titania, zirconia, boron, carbon, compounds such as the carbides, and glass fibre, but some of these materials have been implicated in causing cell lysis and death of animal cells but this would not necessarily preclude their use in this invention as it is known that they may be coated with a  
25 biocompatible coating to prevent such disadvantageous effects. Indeed the provision of such a coating may be advantageous in that it may provide a surface with which transforming DNA may be more conveniently bound, thus improving delivery of the DNA to the interior of the cell. Suitable such coatings may be  
30 synthetic resinous materials, surfactants and benign soluble materials such as alginate or gelatin.

Silicon carbide (SiC) is a ceramic compound used industrially in the manufacture of cutting tools and to reinforce composite materials. Silicon carbide can be produced

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in the form of single crystals which are usually referred to as "whiskers" rather than fibres. These terms are used interchangeably herein.

SiC whiskers of less than 1 $\mu\text{m}$  diameter are ideally suited  
5 for use in this invention because of their high strength and  
good oxidation resistance. In recent years man-made mineral  
fibres have been increasingly exploited as substitutes for  
naturally occurring fibres such as asbestos. This has been  
driven predominantly by the serious health risks associated  
10 with the mining and use of crystalline minerals of the asbestos  
family. Increasingly it is being recognised that these health  
hazards are related, in part, to the morphology of the  
materials being used.

In practice plant cell transformation results from the  
15 mixing of intact cells or tissues with silicon carbide whiskers  
and plasmid DNA. We believe the mechanism of penetration to be  
largely a physical process and that the mixing of whiskers and  
cells must result in breach of the plant cell wall by the  
whiskers. Under the electron microscope many cells can be seen  
20 to have been impaled by the whiskers. We have shown that  
whisker-mediated DNA transfer does not occur (i) with whiskers  
and cells in the absence of mixing or (ii) with cells simply  
mixed with DNA in the absence of whiskers.

The method of the invention is inexpensive, requiring no  
25 sophisticated equipment and few consumables, and a large number  
of samples can be treated quickly. Simple safety precautions  
ensure that there is no risk of exposure to air-borne whiskers.

In fundamental principle, this type of transformation  
utilises a procedure which penetrates the cell wall in a  
30 non-lethal manner. Such methods, then, seek to wound but not  
kill the cells. In investigating possible procedures, it may  
be assumed that if particular method is capable of killing the  
cells then by making the treatment less severe the method may  
be adapted to wound.

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The invention will now be described, by way of illustration, in the following Examples.

Abbreviations used in the Examples:

- BMS Black Mexican Sweet corn  
5 GUS  $\beta$ glucuronidase  
cfu(s) colour forming unit(s), in histochemical GUS assays  
PCR polymerase chain reaction  
2,4-D 2,4-dichlorophenoxyacetic acid  
10 NAA naphthaleneacetic acid  
PCV packed cell volume  
AxB A188xB73 hybrid

Brief Description of the Figures

Figure 1 shows a comparison of two types of silicon carbide whiskers;

Figure 2 illustrates the difference in expression obtained with different types of materials;

Figure 3 illustrates the effect of using different mixers on transformation rate;

20 Figure 4 is a time-course for transformed BMS using p35S-PAC, silicon carbide whiskers and a Vortex Genie mixer;

Figure 5 shows the effect of mixing time on cell viability;

Figure 6 compares transformation rate of BMS with different types of mixers;

25 Figure 7 shows the effect of mixing time on transient GUS expression in BMS;

Figure 8 illustrates the effect on transient expression of pMRP8 in silicon carbide whisker treated corn line A5D1-C6;

Figure 9 shows a Southern blot of five bialaphos resistant 30 GUS expressing callus lines:

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- 1 Lambda EcoRI - HindIII (molecular weight marker)
- 2 Genomic HindIII 1
- 3 Genomic HindIII 2

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- 4 Genomic HindIII 3
- 5 Genomic HindIII 4
- 6 Genomic HindIII 5
- 7 Genomic HindIII negative
- 5 8 Undigested genomic DNA (very faint fogging visible on the photographic film).
- 9 Undigested genomic DNA (very faint fogging visible on the photographic film).
- 10 Uncut plasmid DNA (pBAR-GUS)
- 10 11 Lambda PstI (molecular weight marker); and,  
Figure 10 gives maps of all the plasmids used in the Examples.

The major physical and biological parameters found to influence silicon carbide whisker-mediated transformation of maize cell are described in the Examples. Results are given for transient expression and for stable (integrative) transformation.

The rapidity with which transient expression data can be accumulated makes this a useful tool for the optimisation of the variable parameters of the method. Using GUS as a reporter gene in histochemical assays enables estimation of the number of cells receiving and expressing DNA through the counting of blue colour forming units (cfu's). We have used transient expression (of GUS) as a means of confirming DNA delivery with the whisker transformation approach.

Transient gene expression in its own right can be of value in confirming the functionality of a construct or in performing quantitative construct comparisons and this is the case with whisker-mediated transformation.

30 Transient assays can assist the rapid identification of treatment parameters which bring about an increase in transformation frequency. However, under some circumstances, enhanced transient expression may not translate into an increase in stable transformation efficiency. This is

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particularly the case where cell survival is compromised. In the Examples we have attempted to monitor cell survival where appropriate.

EXAMPLE 1

5        WHISKER TYPE INFLUENCES THE EFFICIENCY OF DNA DELIVERY

Whiskers of <1 $\mu\text{m}$  diameter were assessed with this transformation method. Silicon carbide whiskers from two sources have been compared. Those used in our initial evaluations were obtained from Goodfellow, Cambridge 10 (dimensions 0.5 x 30  $\mu\text{m}$ ). The whiskers used were acquired from Advanced Composite Materials Corporation, Greer, South Carolina (Silar SC-9 whiskers, size range 0.6 x 10-80  $\mu\text{m}$ ).

GUS expression from p35S-PAC was measured histochemically after 2 days for BMS cells treated with these different whisker 15 types using the Gallenkamp Spinmix vortex mixer. The results are shown in Figure 1. A two-fold enhancement was observed in terms of blue colour-forming units for the Silar whiskers.

Scanning EM micrographs showed that the Silar whiskers appeared more uniform than the Goodfellow whiskers with less 20 clumping and debris apparent. These differences may explain the observed increase in expression; there may have been more whiskers in the Silar suspension capable of transforming cells, because of their uniformity. It is also possible that the Silar whiskers may contain less debris or 'toxic' by-products of 25 manufacture.

In another experiment silicon nitride (0.7 x 2-25  $\mu\text{m}$ ) whiskers were compared with Silar whiskers. The results of this comparison, which also included 44 $\mu\text{m}$  glass beads and carborundum are shown in Figure 2.

30 From these results it is evident that only particles with a needle-like morphology deliver DNA effectively under these conditions, silicon nitride may be less effective than SiC in this comparison because of the larger whisker diameter.

The use of different whisker types which may benefit from

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further evaluation. There may be alternative sources of silicon carbide or other whiskers/ fibres with more suitable dimensions that would deliver DNA to cells more efficiently than the types evaluated so far.

5      EXAMPLE 2

MIXING METHOD AND DURATION INFLUENCES TRANSIENT EXPRESSION

Various mixing methods have been investigated in order to increase the level of transient GUS expression whilst monitoring the effect of these treatments on cell viability.

10     (i) BMS cells

Two standard laboratory vortex mixer models (the Gallenkamp Spinmix and Vortex Genie 2) have been directly compared. BMS cells, Silar SC-9 whiskers and p35S-PAC plasmid DNA were mixed for 60 seconds using either the Spinmix or 15 Vortex Genie. Transient expression was monitored by histochemical GUS assay 2 days after treatment. The results are shown in Figure 3.

A two to four-fold increase in GUS expression was found using the Vortex Genie over the levels seen with the Gallenkamp 20 Spinmix. A mean of 700 cfu's were obtained with the Vortex Genie in this experiment, Kaepler et al. (1990) obtained 140 cfu's with BMS under similar conditions. The effect of increased vortex duration on transient expression and BMS cell survival was therefore investigated using the Vortex Genie. A 25 five-fold increase in cfu's was observed between one and ten minutes of vortex treatment (Figure 4).

The largest increase in the number of GUS expressing cells came after three minutes of vortexing, with more than twice the number of cfu's seen after 60 seconds treatment. Observation of 30 cells treated for 10 minutes showed that during vortexing the cell clusters became dissociated into small aggregates and single cells. Cell viability after vortexing was therefore determined to see if increasing vortex time led to cell death (Figure 5).

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An initial drop in viability of about 20% was observed, with a further reduction of approximately 5% between the one and ten minute vortex times.

The effect of extended vortex duration (180 and 600  
5 seconds) on the recovery of stably transformed callus has also been investigated (see below).

BMS cell/whisker agitation using an oscillating dental amalgam mixers (Mixomat and Silomat) has been evaluated. The results in Figure 6 show that when vortex time with the Spinmix  
10 was extended from 35 to 70 seconds the number of GUS cfu's increased. However, with the amalgam mixers the longer treatment time reduced GUS expression. Observation of the cells showed that after 60 seconds of Mixomat treatment there was significant cell dissociation and death. A time course of  
15 Mixomat treatments from 1 to 30 seconds was performed with BMS, the results of which are shown in Figure 7. GUS cfu's increase linearly up to 5 seconds of treatment but then reduce dramatically beyond 10 seconds, presumably as a result of reduced cell viability. To assess if the increased transient  
20 expression seen after 5 seconds of Mixomat treatment translated into more stable transformation events an experiment to compare 1 versus 5 seconds of treatment was performed.

(ii) AxB suspension cultures

An investigation into alternative mixing methods was  
25 undertaken comparing the Vortex Genie with the Mixomat amalgam mixer on the embryogenic suspension lines A5D1-C5 and A5D1-C6. It is apparent from Table 1 that, as with BMS, the Mixomat gave a significantly higher frequency of transiently expressing cells than the vortex mixer.

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TABLE 1

Effect of mixing method on transient expression of p35S-PAC  
(cfu's) in suspension lines A5D1-C5 and C6

| Mixing method | Vortex Genie |     | Mixomat |      |
|---------------|--------------|-----|---------|------|
| Cell Line     | C5           | C6  | C5      | C6   |
| Rep 1         | 112          | 176 | 969     | 1895 |
| Rep 2         | 145          | 239 | 832     | 1049 |

Mixing times used were 3 minutes for the Vortex Genie and 5 seconds for the Mixomat.

To determine the optimum period for Mixomat treatment, a time course experiment was performed.

5 Table 2 illustrates the results, demonstrating that a treatment time of 5 seconds provided the maximum number of transiently expressing cells for cell lines C5 and C6.

TABLE 2

Effect of Mixomat time course on transient expression of p35S  
PAC in suspension lines A5D1-C5 and C6

| Agitation Time<br>(seconds) | C5  | C6   |
|-----------------------------|-----|------|
| 1                           | 387 | 940  |
| 5                           | 792 | 2204 |
| 10                          | 540 | 897  |
| 20                          | 207 | 775  |
| 30                          | -   | 301  |

No osmotic pre-treatment was used and additional medium was excluded.

15 In order to evaluate the effect of Mixomat treatment on cell survival, C5 and C6 suspension cells were subjected to the same Mixomat time course with cell viability measured after 24 hours.

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Up to 50% loss of viability occurred as a result of Mixomat treatment for 5 seconds. After one second of mixing (the minimum time setting on the machine), cell mortality was less than 25% and levels of transient expression (as shown in Table 5 2) were still reasonable, hence this period of treatment was used as standard in subsequent transformation experiments involving the Mixomat.

EXAMPLE 3

OSMOTIC TREATMENT OF CELLS

10      (i) AxB suspension cultures

Since the application of osmotic stress to target cells prior to particle bombardment (in the Biolistics method) is known to result in increased frequencies of both transiently expressing cells and stable transformants, an investigation 15 into the utility of osmotic treatments prior to, and/or following whisker-mediated transformation of A5D1-C6 was undertaken.

The osmotic medium used was identical to that used before particle bombardment (H9CP+ with 45.4 g/l mannitol and 45.4 g/l 20 sorbitol). Treatment consisted of immersion of 250 mg cells per replicate in 1 ml osmotic medium for 30 minutes. Controls were immersed in unamended H9CP+ for the same period.

Results given in Table 3 clearly demonstrate that osmotic pretreatment is beneficial with respect to transient 25 transformation. It would appear however that the treatments following whisker mixing offered no advantage.

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TABLE 3

Influence of osmotic treatment on transient expression of GUS  
from p35S-PAC in suspension line A5D1-C6

| Replicate | Control<br>(cfu's) | Pretreatment<br>(cfu's) | Pre + Post<br>treatment<br>(cfu's) | Post-<br>treatment<br>(cfu's) |
|-----------|--------------------|-------------------------|------------------------------------|-------------------------------|
| 1         | 459                | 1184                    | 1023                               | 255                           |
| 2         | 396                | 1302                    | 1395                               | 445                           |
| 3         | 565                | 1489                    | 1341                               | 436                           |

Mixing treatment was 1 second with the Mixomat

Various modifications to this method have also been assessed. These include reduction in the duration of osmotic treatment and treatment in a flask with shaking rather than in 5 the Eppendorf tube. Results are presented in Table 4 for some of these experiments:

TABLE 4

Effect of various osmotic treatments on transient GUS  
expression in regenerable culture

|       |              | Pre-treatment |        |                  |        |        |  |
|-------|--------------|---------------|--------|------------------|--------|--------|--|
|       |              | In Eppendorf  |        | In Shaking Flask |        |        |  |
| Expt. | Cell<br>Line | 10 min        | 30 min | 0 min            | 10 min | 30 min |  |
| 1     | C6           | 928           | 973    | 626              | -      | -      |  |
| 2     | C6           | -             | 768    | 296              | -      | 1284   |  |
| 3     | C12          | -             | -      | 270              | 955    | 1187   |  |

10 These results show the beneficial effect of performing osmotic treatment in a shaking flask. It may be that this improvement is a consequence of increased cell aeration and

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survival. A further benefit of flask osmotic treatment is improved experimental (time/effort) efficiency.

(ii) Effect of Osmotic Treatments on BMS cultures

Surprisingly, osmotic pre-treatment of BMS almost totally  
 5 eliminated DNA delivery as judged by transient GUS expression (maximum of 25 cfu's). Microscopic observation of cells immediately after treatment suggested that this was the result of excessive cell plasmolysis. Since these same conditions work well with regenerable lines, it is apparent that BMS responds  
 10 differently with respect to osmotic conditioning, presumably because of differences in cell size and degree of vacuolation.

EXAMPLE 4

AGE OF CELL SUSPENSION

The influence of suspension age (relative to subculture) on  
 15 competence for transformation has been investigated for A5D1-C8 and C12. Results are shown in Table 5.

TABLE 5

Transient expression in A5D1 lines at different stages relative to subculture

|     | Day after subculture (cfu's) n=3 |         |        |        |        |
|-----|----------------------------------|---------|--------|--------|--------|
|     | Day 0                            | Day 1   | Day 2  | Day 3  | Day 4  |
| C8  | 638±84                           | 938±51  | 448±27 | 333±40 | 398±28 |
| C12 | 357±79                           | 590±104 | 363±25 | 244±14 | 248±23 |

20 Cells were osmotically pre-treated for 30 minutes on the shaker. Mixing was performed with the Vortex Genie for 60 seconds.

Analysis of variance on these results indicated a significant day effect for both cell lines.

25 Mean transient counts at day 1 were significantly higher than the other suspension ages tested. Days 3 and 4 did not differ significantly from each other. Day 0 cfu's were

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significantly higher than day 4 for C8 but not for C12. It may be of value to identify the optimum suspension age for each new cell line treated, assuming that there is a direct, positive correlation between cfu's and stable clone production for this

5 cell culture characteristic.

For BMS, optimum suspension age was found to be 2 days, during exponential growth of the culture.

EXAMPLE 5

PRE-MIXING OF WHISKERS AND DNA

10 We have evaluated the timing of DNA/whisker interaction to see if this affects the efficiency of DNA delivery to A5D1-C6 suspension cells. Normally whiskers and DNA are vortex mixed for 60 seconds prior to addition of cells. Various pre-mixing periods were assessed and compared with no pre-mixing, the  
15 results are shown in Figure 8. Mixing involved 1 second of Mixomat treatment. The plasmid was pMRP8

From these results it is apparent that pre-mixing of whiskers with DNA is not necessary to achieve efficient DNA delivery to C6 cells. This does not preclude the possibility  
20 that a rapid spontaneous interaction occurs between whiskers and DNA based on their relative charges.

EXAMPLE 6

CONFORMATION OF PLASMID DNA

Linearised and supercoiled DNA have been compared in BMS.  
25 The results are shown in Table 6.

TABLE 6

Comparison of supercoiled versus linearised p35S-PAC in BMS cells

| DNA form    | Mean cfu's | Fluorimetric GUS nMol 4-Mu/mg/hour |
|-------------|------------|------------------------------------|
| Supercoiled | 505        | 30.3                               |
| Linearised  | 301        | 4.7                                |

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Values are the mean of 3 replicates. Vortex Genie (60s) treatment was used.

It is clear from this result that supercoiled DNA is preferable to linearised DNA in terms of transient GUS expression. This is in broad agreement with published work on "direct gene transfer." The difference seen here in fluorometric GUS activity is greater however than we saw when the same comparison was performed in AxB suspension protoplasts.

10 EXAMPLE 7

ZYGOTIC EMBRYOS, EMBRYOGENIC CALLUS AND PROTOPLASTS

(i) Whisker treatment of immature maize zygotic embryos

Because of the ease of plant regeneration from responsive genotypes, zygotic embryos are an attractive target tissue in corn for transformation. An investigation into the utility of the whisker method for DNA transfer to embryos was undertaken.

Initial studies used the fluorometric GUS assay to examine the outcome of enzyme pretreatment and vortex time course on whisker treatment of 11 day old A188 embryos. Neither degrading the cell walls nor increasing the vortex time resulted in increased transient expression, although samples showing up to 23 times background GUS activity were identified.

Comparison of Mixomat treatment for 1 or 3 seconds with vortexing for 5 minutes (using 11 day old FH24 embryos) identified vortexing without medium present to be the least damaging treatment and to give the highest frequency of cfu's per embryo in histochemical assays. Whilst up to 85% of embryos were found to have blue spots, the mean was only 3 per embryo (range 1-12). It is assumed that only cells on the surface of the embryo will receive DNA using whiskers.

Evaluation of osmotic pretreatment for 30 or 60 minutes with 11 day old UE95 embryos identified a trend of decreasing transient expression with increasing pretreatment period (55%

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and 37% respectively of embryos had cfu's).

(ii) Whisker treatment of type III callus lines

"Type III" Be70 and Be81 callus lines were used in transformation assessments with whiskers using the Mixomat. To 5 ensure that both lines received the optimum period of Mixomat treatment, a time course experiment was performed. No osmotic pretreatment was used in this experiment, the results of which are presented in Table 7.

TABLE 7

- 10 Mixomat time course applied to Be70 and Be81 type III callus lines

| Agitation Time<br>(seconds) | Be70<br>GUS cfu's | Be81<br>GUS cfu's |
|-----------------------------|-------------------|-------------------|
| 1                           | 28                | 21                |
| 5                           | 63                | 76                |
| 10                          | 54                | 34                |
| 20                          | 40                | 11                |
| 30                          | 25                | 16                |

From the time points investigated, the 5 second treatment resulted in maximum transient expression for both lines.

- 15 Subjecting the type III tissue to 30 minutes osmotic pretreatment prior to transformation (Mixomat 1 second) resulted in a 6 (Be70) and 8 (Be81) fold increase in transient expression over controls (Table 8).

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**TABLE 8**  
**Effect of osmotic pretreatment of type III lines**

| Line | Control cfu's | Pretreatment cfu's |
|------|---------------|--------------------|
| Be70 | 19            | 144                |
|      | 18            | 168                |
|      | 24            | 133                |
| Be81 | 38            | 282                |
|      | 25            | 130                |
|      | 22            | 297                |

**(iii) Whisker treatment of protoplasts**

We were interested to learn whether whiskers could deliver DNA to corn protoplasts. An experiment was performed with PEG uptake as a control using the conditions shown in Table 9.

**5 TABLE 9**

**GUS expression from BxA protoplasts with whiskers and PEG uptake**

| Treatment Number | DNA | Whiskers | Vortex | GUS Expression nMol/mg/hour |
|------------------|-----|----------|--------|-----------------------------|
| 1                | +   | +        | +(1)   | 385                         |
| 2                | +   | +        | +(2)   | 520                         |
| 3                | +   | PEG      | -      | 7618                        |
| 4                | +   | -        | -      | 0                           |
| 5                | +   | -        | +      | 0                           |
| 6                | -   | +        | +      | 0                           |

The Vortex Genie II was used at two speed settings:

1 setting= shaker 3

10 2 setting= vortex 1

Values are the mean of three replicates

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These results show that whisker treatment of protoplasts results in DNA delivery albeit at a lower rate than that achieved with PEG treatment. This would suggest that cell/protoplast penetration by whiskers occurs rather than 5 abrasion which would result in loss of protoplast viability to the exclusion of GUS expression.

EXAMPLE 8

VERIFICATION OF STABLE TRANSFORMATION IN BMS

The first experiment involved a repeat of the conditions 10 described by Kaepller et al. (1992) with the exception that the Gallenkamp Spinmix was used and selection was performed using medium containing Bialaphos rather than BASTA. Selection with 1 mg/l bialaphos was applied 48 hours after treatment, after 7 days at this level it was increased to 5 mg/l.

15 A mean of 32 bialaphos-resistant colonies per treatment were recovered in this experiment. Seventy per cent of these colonies expressed GUS and were PCR positive. The remaining colonies (19 in total) did not express GUS. PCR established that 14 of the 19 colonies contained the GUS gene ie. they were 20 transformed but non-expressers. The remaining 5 GUS-negative colonies were also PCR negative ie. they were "escapes".

In summary, 92.0% of all the colonies contain the GUS gene in some form and these colonies were stably transformed (ie. 29 stably transformed colonies were obtained per treatment).

25 Five of the GUS expressing PCR-positive lines were used in Southern analysis.

The resulting blot (Figure 9) showed that the BAR gene was present in the nuclear genome of all five of the colonies which were used in Southern hybridisation. Rearrangement of the BAR 30 gene also appears to have taken place in some of the colonies.

The number of stably transformed lines per treatment obtained in this experiment (29) is clearly higher than that obtained by Kaepller et al. (1992). This could be due to the

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use of bialaphos rather than BASTA selection or may be attributed to the different BMS cell line used. A transient expression experiment performed at the same time as this stable transformation study gave an average of 100 cfu's per 5 treatment, indicating a transient to stable transformation ratio of nearly 30% compared with the 10% obtained by Kaeppeler et al.

EXAMPLE 9

EFFICIENCY OF STABLE TRANSFORMATION IS INFLUENCED BY SELECTION

10 CONDITIONS

The choice of level and timing of selective agent application is a key consideration in the development of any transformation system. It is important to ensure that the balance between selection stringency and the growth of non 15 transformed tissue is maintained without reducing the growth of transformed callus.

A second stable transformation experiment was performed with BMS to evaluate the effect of initial bialaphos selection level on the number of callus lines subsequently recovered.

20 Three levels of bialaphos selection were compared; 1, 2 and 5 mg/l. Here, selection commenced one day after treatment with whiskers and continued for 7 days, after which the selection level for all treatments was maintained at 5 mg/l bialaphos.

25 A total of 517 bialaphos-resistant colonies were recovered from 16 plates (16 treatments) in this experiment (Table 10).

Approximately 90% of all the colonies recovered from the plates were GUS expressing, irrespective of the level of bialaphos selection applied.

30 From these results it can be seen that the 1mg/l initial bialaphos selection produced the highest number of transformed callus lines (43 per treatment). This concentration of bialaphos has since been adopted in our standard BMS/whisker transformation protocol.

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TABLE 10

Effect of bialaphos selection level on recovery of stably transformed BMS callus

| Initial Level of Bialaphos selection (mg/litre) | 1        | 2        | 3       |
|---|----------|----------|---------|
| Number of Treatments                            | 7        | 7        | 2       |
| Number of callus lines selected                 | 304      | 173      | 39      |
| Callus lines                                    | 43       | 25       | 19      |
| Histochemical GUS assay - positive              | 278(91%) | 157(91%) | 33(85%) |
| Histochemical GUS assay - negative              | 26(9%)   | 16(9%)   | 6(15%)  |

The Gallenkamp Spinmix was used to mix cells, whiskers and 5 DNA for 60 seconds

Selection was initiated at the levels shown one day after whisker treatment

Selection was increased to 5mg/l after seven days at this level

10 EXAMPLE 10

EFFECT OF MIXING DURATION AND METHOD ON STABLE BMS TRANSFORMATION

(i) Vortex duration and vortex model

An experiment to evaluate stable transformation of BMS 15 following 60,180 and 600 seconds of vortex treatment (using the Vortex Genie II) was performed. This was prompted by transient expression results which showed a two-fold increase in cfu's when vortex duration was increased from 60 to 180 seconds and a five-fold increase from 60 to 600 seconds.

20 After 60 seconds of Vortex Genie mixing a mean of 73

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bialaphos-resistant callus lines were obtained per treatment using the selection scheme arrived at above. This compares favourably with the number of calli obtained using the Gallenkamp Spinmix (mean 43 lines per treatment).

5 Increasing the vortex period to 180 seconds did not increase the number of callus lines obtained (75 per treatment developed). The increase in transient expression does not therefore translate into an increase in stable transformation rate in this case, presumably as a result of reduced cell  
10 survival after the longer vortex period.

Following 600 seconds of mixing, no stably transformed lines were recovered and the re-growth of callus on unselected plates was very poor compared with controls.

These results highlight the importance of considering cell  
15 survival when attempting to equate transient expression with stable transformation for a given treatment.

(ii) Mixomat treatment

An experiment to evaluate stable BMS transformation after Mixomat (amalgam mixer) treatment was also performed. One  
20 second of mixing was used and the effect of culture medium inclusion/exclusion was assessed. Transient expression results suggested that the exclusion of additional culture medium resulted in an increase in cfu's, presumably because of an increase in the number or force of cell-whisker collisions.

25 A mean of 65 bialaphos-resistant callus lines were recovered from each treatment after 1 second of Mixomat treatment with medium present. This figure increased to 160 callus lines per treatment when medium was excluded, confirming the earlier transient expression result. This represents the  
30 highest number of stably transformed BMS callus lines obtained per treatment with whisker transformation to date.

After 5 seconds of Mixomat treatment there was a dramatic reduction in the number of stably transformed lines obtained (2 per treatment in the absence of medium). Transient expression

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for 5 seconds of treatment was around three-fold higher than that for 1 second of treatment.

There is probably scope for optimisation of stable transformation rates through the exploration of alternative 5 mixing methods and periods. However our results clearly indicate that transient expression alone does not always enable improved conditions to be identified. Careful consideration of the effect of mixing conditions on cell survival for each culture line must be made.

10 EXAMPLE 11

STABLE TRANSFORMATION OF REGENERABLE CULTURES

A series of experiments has been carried out with regenerable suspension cultures. A total of nine callus lines resistant to 1 mg/l bialaphos have developed and plants have 15 been regenerated from 6 of these. The experiments which have resulted in callus production are summarised in Table 11.

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TABLE 11Summary of bialaphos-resistant clones obtained from regenerable suspensions

| Cell Line | Mixing | Callus Analysis |          | Plants | Clone Name |
|-----------|--------|-----------------|----------|--------|------------|
|           |        | GUS assay       | PCR(GUS) |        |            |
| C8        | MM     | +               | +        | +      | UC2        |
| C8        | MM     | -               | +        | +      | RU2        |
| C8        | VG     | +               | +        | +      | RR2        |
| C6        | VG     | +               | +        | +      | UB2        |
| C8        | VG     | +               | nd       | +      | UJ2        |
| C12       | VG     | +               | nd       | +      | UA2        |
| C12       | VG     | -               | nd       | +      | UI2        |
| C8*       | VG     | +               | nd       | +      | UZ15       |
| C8        | MM     | +               | nd       | +      | WB2        |
| C12**     | VG     | -               | nd       |        |            |
| C13       | VG     | +               | nd       |        |            |

Mixing treatments: MM; Mixomat (1 second), VG; Vortex Genie (60 seconds)

nd; not determined

Named clones have produced plants currently in the glasshouse

- 5 The transforming plasmid was pBAR-GUS except for \* which was from pMRP7 and \*\* which was from pMRP8.

Various osmotic treatments were assessed in these experiments.

- Transient expression was monitored in most of the 10 experiments summarised in Table 11, however a clear

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relationship between treatment, transient expression and clone production was not apparent in these experiments.

EXAMPLE 12

ANALYSIS OF BIALAPHOS-RESISTANT CALLUS

5 Table 10 summarises the results of GUS and PCR assays carried out on the 9 clones obtained to date. Most of the clones are GUS expressing and 4/4 of those assayed by PCR (for GUS) were positive.

EXAMPLE 13

10 REGENERATION AND ANALYSIS OF TRANSGENIC PLANTS

Using the protocol described below in respect of regeneration from bialaphos-resistant colonies, plants have been regenerated from six of the nine clones obtained (indicated in Table 10). Plants from five of these six are currently in the glasshouse. There are 18 plants from clone RR2 and 20 plants from clone RU2.

Analysis:

(i) RR2

Two plants have been BASTA "leaf paint" assayed; both 20 were positive.

Ten plants have been GUS assayed (histochemical assay on leaf samples); all were positive.

One plant has been PCR assayed (for GUS) and was positive.

(ii) RU2

25 One plant has been leaf paint assayed and was positive.

Eight plants have been GUS assayed; all were negative (the callus was also non-expressing).

MATERIALS AND METHODS

The materials and methods used in the Examples are:

30 CELL CULTURES

Black Mexican Sweet corn (BMS) culture

A finely dividing, non-regenerable cell suspension of Black Mexican Sweet corn (BMS) was used. This line has been

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maintained in our laboratories for over 5 years.

Subculturing of BMS is performed every 7 days by transferring 10 ml of culture into 80 ml fresh BMS medium, the cultures are grown at 25°C on a rotary platform shaker (120 rpm).

Experiments were carried out on 2 day old cell suspensions. A packed cell volume of 250 µl was used for each treatment. This was achieved by centrifuging the contents of a flask of BMS at 600 rpm for 3 minutes, removing the supernatant and adding the same amount of fresh BMS medium to packed cell volume. 500 µl of this suspension was then used for each treatment (250 µl of cells and 250 µl of medium).

#### Embryogenic Corn suspension cultures

AxB suspensions derived from cryopreserved tissue (generic designation A5D1) were used for whisker treatment. The cultures are subcultured twice weekly by transferring cells and conditioned medium into fresh H9CP+ medium. Cells are grown at 28°C, 125 rpm.

Culture medium from a 1 day old culture was, where appropriate, replaced with fresh H9CP+ plus osmoticum (0.5M sorbitol/ mannitol) and returned to 125 rpm for 30 minutes.

#### AxB CELL SUSPENSION INITIATION AND CELL LINE DERIVATION

Zygotic embryos, 10-12 day old, from a greenhouse-grown A188xBe70 hybrid were plated on N6 base medium containing 6mM proline, 2% sucrose, 2mg/l 2,4-D and 0.3% Gelrite.

Proliferating Type II structures from a single responding embryo (A5D1) were cultures on the same medium and the callus used to initiate a cell suspension. Approximately 3g of callus were added to 22ml liquid H9CP+ and 1ml of coconut water and the flask maintained at 28°C, 128rpm and subcultured every 3½ days.

#### DERIVATION OF CELL CULTURES USED IN WHISKER EXPERIMENTS

A5D1-C6: derived from a cryopreserved A5D1 suspension. Thawed callus was used to initiate the susension two weeks

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after thawing. At the time of whisker treatment the suspension was well established and consisted of small aggregates. The total time in suspension was around 12 months.

A5D1-C8: derived from a cryopreservation of A5D1-C6  
5 suspension. The thawed callus was used to initiate the suspension A5D1-C8. The suspension was characterised by a dispersed but large-aggregate type. The total time in suspension was 10-11 months.

A5D1-C12: derived from cryopreserved A5D1 which had spent  
10 8-10 months in suspension at the time of used in whisker transformation. It is a medium-sized aggregate suspension.

#### ZYGOTIC EMBRYOS

Corn inbred line PH24 was self-pollinated and embryos excised at 10-15 days after pollination. These embryos were  
15 used in whisker-mediated transformation.

Embryos at the appropriate stage of development may be cultured on a suitable medium and they will form an embryogenic callus from which plants may be directly regenerated. This may be achieved with the majority of corn genotypes via a Type I  
20 callus (compact nodular tissue).

Certain genotypes will form Type II and Type III embryogenic callus from embryos either directly or from another callus type. Type II is composed of somatic embryos in various stages of maturation but early, that is, stalked embryos on  
25 basal callus is preferentially selected at subculture.

Type III callus is formed only rarely and is much more friable, that is, it is easily dispersed and does not have any distinct embryos on it. This is ideal tissue for transformation because it is accessible for DNA delivery and will readily form  
30 cell suspension cultures. It has to be selected visually and preferentially at subculture.

#### PROTOPLASTS

The protoplasts referred to herein were isolated from a B73xA188 embryo callus (Type III)- derived cell suspension

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culture. The protoplasts were obtained by a standard procedure with enzymatic digestion of the suspension in 2% cellulase RS and 0.2% pectolyase Y-23.

PLASMID DNA

- 5 p35S-PAC was used for most of the transient expression experiments. Plasmid p35S-PAC contains the cauliflower mosaic virus (CaMV) 35S promoter and the intron 1 of maize alcohol dehydrogenase (Adh1) fused to the GUS (uid A) gene and the CaMV polyadenylation signal.
- 10 pBAR-GUS was used for most of the stable transformation experiments. This plasmid contains the BAR gene fused to the 35S CaMV promoter and the intron 1 of maize Adh1 joined in opposite orientation to the GUS gene which is under the control of the Adh1 promoter and intron 1 of maize Adh1
- 15 Figure 10 gives maps of all the plasmids used in these experiments.

PREPARATION OF SILICON CARBIDE WHISKERS

- Dry whiskers were always handled in a fume cabinet, to prevent inhalation and possible lung damage. These whiskers may 20 be carcinogenic as they have similar properties to asbestos. The Silar SC-9 whiskers were provided by the Advanced Composite Material Corporation Greer, South Carolina, USA. The sterile whisker suspensions were prepared in advance as follows. Approximately 50mg of whiskers were deposited into a pre 25 weighed 1.5 ml Eppendorf tube, which was capped and reweighed to determine the weight of the whiskers. The cap of the tube was perforated with a syringe needle and covered with a double layer of aluminium foil. The tube was autoclaved (121°C, 15psi, for 20 minutes) and dried. Fresh whisker suspensions were 30 prepared for each experiment, as it had been reported that the level of DNA transformation when using fresh suspensions was higher than that of older suspensions (Kaepller et al. 1992). A 5% (weight/volume) whisker suspension was prepared using sterile deionised water. This was vortexed for a few seconds to

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suspend the whiskers immediately before use.

DNA TRANSFORMATION INTO CELLS

All procedures were carried out in a laminar air flow cabinet under aseptic conditions. The DNA was transformed into 5 the cells using the following approach. Specific modifications to this method are indicated in the text.

Cell and whisker suspensions were pipetted using cut down Gilson pipette tips. 100 $\mu$ l of fresh BMS medium (see appendix 1) was measured into a sterile Eppendorf tube. To this was added 10 40 $\mu$ l of the 5% (w/v) whisker suspension and 25 $\mu$ l (1mg/ml) of the plasmid DNA, which was vortexed at top speed for 60 seconds using a desktop vortex unit (Vortex Genie 2 Scientific industries, Inc). Immediately after this period of vortexing, 500 $\mu$ l of the cell suspension was added ie 250 $\mu$ l of packed cells 15 (see 3.1 for preparation of cell suspension). The Eppendorf tube was then capped and vortexed at top speed for 60 seconds in an upright position. The same procedure was used to transform the other cell lines.

CELL VIABILITY

20 After the cells had been treated and incubated, 2ml of fluorescein diacetate (3 drops of 5mg/ml FDA to 10 ml of water) was added to each sample and left for 5 minutes. The total number of cells and the number of fluorescent cells were counted, using a haemocytometer slide viewed under ultra violet 25 light. From this the percentage of living cells was determined.

GUS ASSAYS

For BMS, following vortexing, 500 $\mu$ l of BMS medium was added to each tube, the contents of which was poured into a 50 x 20mm disposable petri dish. A further 1 ml of BMS medium was 30 pipetted into the tube, gently shaken and poured into the petri dish, to ensure that all the cells had been removed from the tube. The plates were sealed with Nescofilm and incubated in the dark for 48 hours at 25°C.

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Fluorometric GUS assays were performed and results calculated according to the method produced by Caroline Sparks (available on request).

Histochemical assays were performed using 2 ml of the  
5 following assay buffer /sample:

50 ml 0.1 M dibasic/monobasic sodium phosphate  
80 mg Potassium ferricyanide  
105 mg Potassium ferrocyanide  
0.06% Triton X-100  
10 0.1% Dimethyl sulphoxide  
500µl X-gluc (5% solution in DMF)

Tissue was incubated for 24 hours at 37°C.

SELECTION OF STABLE TRANSFORMANTS

BMS

15 Samples of BMS cells treated with pBAR-GUS and silicon carbide whiskers and control samples treated with whiskers alone, were dealt with as follows:

i) Immediately after vortexing the sample in the Eppendorf tube 500µl of fresh BMS medium was added.

20 ii) The contents of the tube were poured onto a 12.5 cm disc of Whatman no.2 filter paper, overlying 75 ml of BMS medium (0.6% Sea Plaque agarose), in a 140 x 25 mm petri dish.  
iii) A further 1 ml of BMS medium was pipetted into the tube, shaken briefly and poured onto the plate, in order to remove

25 all the cells from the tube.

iv) The plates were agitated to distribute the cells as a thin layer over the filter paper, sealed with Nescofilm and incubated in the dark at 25°C for 24 hours.

v) After this period of incubation the filter paper and the  
30 overlying cells were transferred onto the selection medium.

This comprised 90 ml of BMS medium solidified with 0.6% Sea Plaque agarose, containing 1mg/litre of bialaphos in a 140 x 25 mm petri dish. The sealed dishes were incubated for 7 days at 25°C.

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- vi) After this period of selection on 1mg/litre of bialaphos the filter paper and the overlying cells were transferred onto selection medium containing 5mg/litre of bialaphos.
- vii) The plates were sealed with Nescofilm and incubated in  
5 the dark at 25°C.
- viii) The support filter papers and overlying cells were transferred onto fresh selection medium with 5mg/l bialaphos at two week intervals.
- ix) After approximately 3 weeks of selection, putatively  
10 transformed cells growing on the selection medium were observed.
- x) The resistant colonies were placed directly onto 2 ml of 2 mg/litre bialaphos selection medium (one colony per well in 25 well plates), once they had grown to approximately 3 mm in  
15 diameter. Subculturing was then carried out every two weeks onto fresh selection medium.
- A5D1 suspension cultures
- i) Treated cells were transferred to 4.7 cm diameter Whatman no.1 filters overlying 12 ml of N6 medium (2 mg/l 2,4-D)  
20 solidified with 3 g/l Gelrite in 5 cm dishes and cultured at 28°C in the dark.
- ii) After 7 days the filters were transferred to fresh N6 medium containing 1 mg/l bialaphos.
- iii) After a further 7 days the filters were transferred again  
25 to fresh N6 with 1 mg/l bialaphos.
- iv) Tissue from one filter was dispersed in 5 ml of cool N61B medium with 3 g/l Sea Plaque agarose. The tissue/medium mixture was then spread onto the surface of two plates of N61B medium solidified with Gelrite.
- 30 v) Bialaphos-resistant callus was picked from embedded tissue 5-6 weeks later.

VERIFICATION OF STABLE TRANSFORMATION

Histochemical gus assay

A histochemical gus assay was performed on each individual

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BMS colony once they had grown to approximately 5 mm in diameter on the 2 mg/litre bialaphos selection medium. The degree of staining of the gus positive colonies was observed. If colonies were gus negative for this assay it was possible 5 that they were either escapes which could tolerate 5mg/litre of bialaphos, or that they were not expressing the GUS gene. In order to verify if these colonies were gus negative transformants or if they were "escapes", they were assayed with PCR.

10 Polymerase Chain Reaction (PCR)

PCR was used to amplify an internal region within the GUS gene consisting of 496 base pairs, using 2 oligonucleotides each consisting of a sequence of 27 bases.

PLANT REGENERATION FROM BIALAPHOS-RESISTANT CLONES

15 After picking from selection plates, callus was bulked on N61B medium. At subculture, type II embryogenic tissue from a stock plate was transferred to MS medium with 1 mg/l NAA and 6% sucrose (25°C, dark) for 2-3 weeks. Mature, opaque structures were moved to the light on MS medium with 0.25 mg/l NAA.

20 Developing plantlets (ie. with both shoot and root visible) were transferred to 1/2 strength MS medium with 3% sucrose and no hormones in air exchange vials until the roots were well developed. They were then moved into hydroponics in the glasshouse, then into peat pots and finally into 3 gallon pots

25 for growth to maturity.

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CLAIMS

1. A method of introducing a nucleic acid into a plant cell, comprising providing a culture of plant cells, placing proximate the plant cell culture a multiplicity of elongate needle-like bodies and subjecting the said cell and bodies to physical motion so as to create relative movement, and thereby collisions, between the bodies and the cells whereby, on collision of a body and a cell, the cell wall is breached providing means for ingress of nucleic acid to the cell.
2. A method according to claim 1, in which the needle-like bodies are selected from the group consisting of silicon carbide whiskers and silicon nitride whiskers.
3. A method according to claim 1 or claim 2, in which the said bodies and said nucleic acid are pre-mixed and thereafter added to the cell culture.
4. A method according to claim 1 or 2 or 3, in which the physical motion applied to the cells, bodies and nucleic acid is rotational motion.
5. A method according to claim 1 or 2 or 3, in which the physical motion applied to the cells, bodies and nucleic acid is

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reciprocating or oscillating motion.

6. A method according to any preceding claim, in which the nucleic acid is a DNA capable of genetically transforming the said cell.
7. A method as claimed in claim 6, wherein the said DNA is linear or supercoiled plasmid DNA.
8. A method as claimed in claim 6 or claim 7, in which the said DNA includes a selectable marker gene.
9. A method as claimed in claim 8, in which the said selectable marker gene specifies resistance to bialaphos.
10. A method according to any preceding claim, in which the said cell culture is of plant cells capable of regeneration into whole plants.
11. A method according to claim 10, in which the said cell culture is a suspension culture of regenerable cells of Zea mays.
12. A method as claimed in any of claims 1 to 9, in which the cell culture is of zygotic embryos.
13. A method as claimed in any of claim 1 to 9, in which the cell culture is of embryogenic callus.

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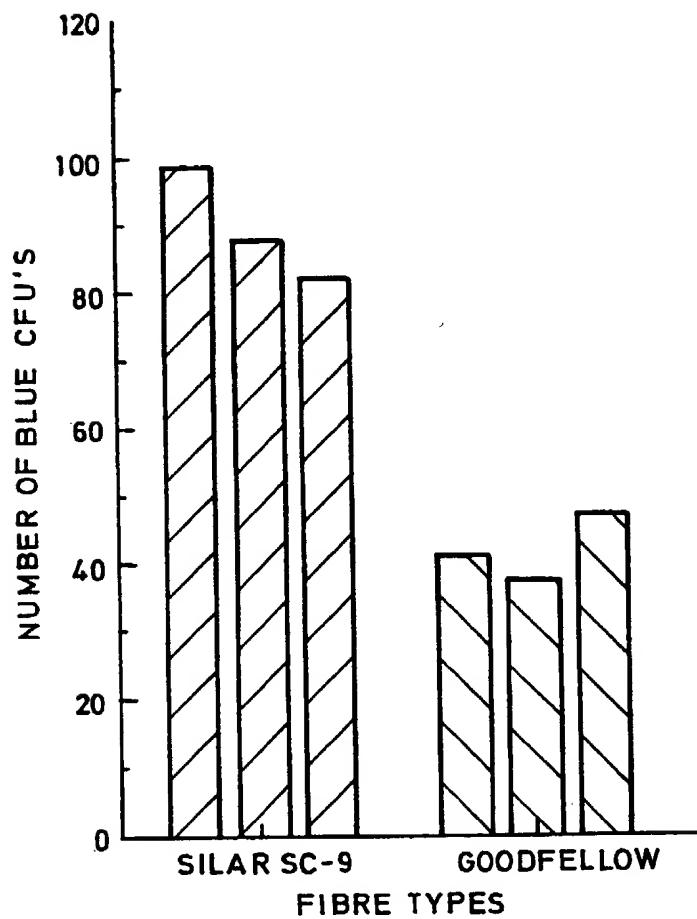
14. A method as claimed in any of claim 1 to 9, in which the cell culture is of plant cell protoplasts.
15. A method as claimed in any preceding claim, in which the said cell culture is subjected to osmotic stress prior to contact with the needle-like bodies.
16. A method for the production of a transgenic monocotyledonous plant, comprising providing a culture of cells of the said plant of a type which is regenerable into whole plants, placing proximate the plant cell culture a multiplicity 5 of elongate needle-like bodies and plasmid DNA containing a gene gene of interest and a selectable marker gene, subjecting the said cells and bodies to physical motion so as to create relative movement, and thereby collisions, between the bodies and the cells whereby, on collision of a body and a cell, the cell wall 10 is breached providing means for ingress of nucleic acid to the cell, transferring the cells to a regeneration medium containing a selection agent appropriate for the marker gene and recovering surviving plantlets from the medium.
17. A method as claimed in claim 16, in which the said plant is Zea mays.

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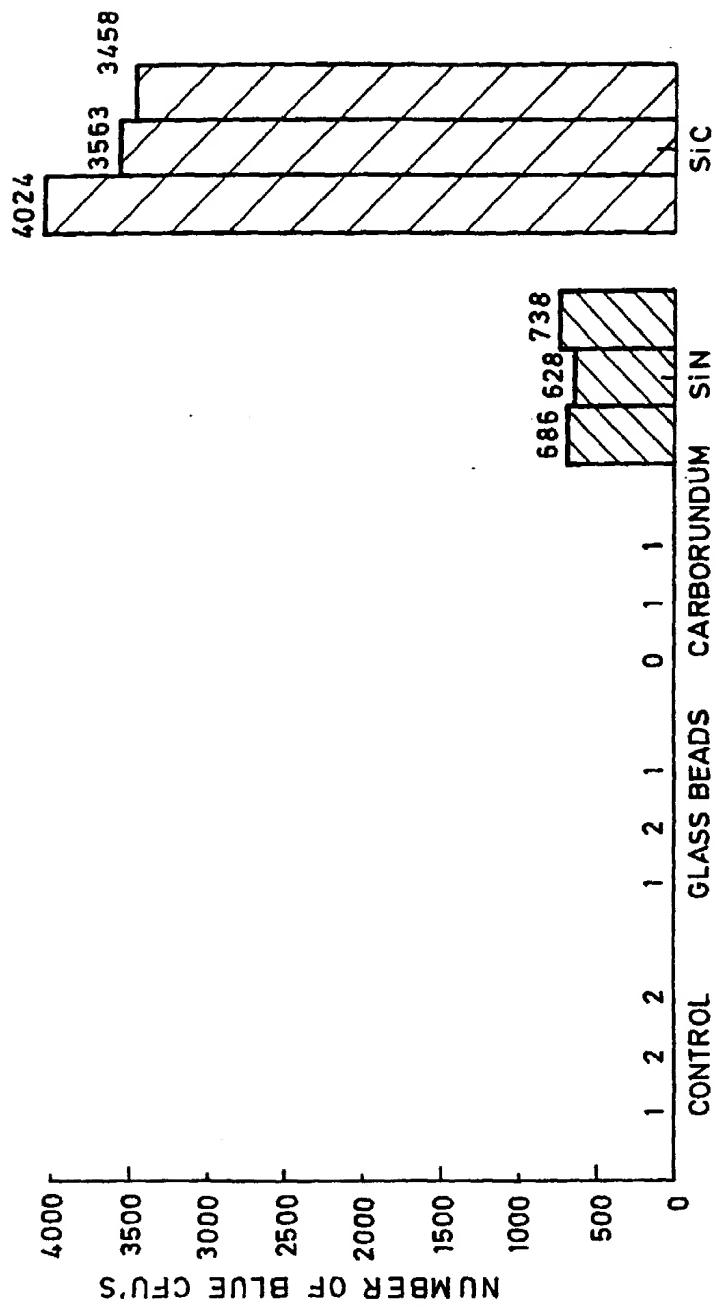
**FIG. 1**

COMPARISON OF SILLAR SC-9 FIBRES  
AND 0.5x 30um GOODFELLOW FIBRES  
(GALLENKAMP SPINMIX)

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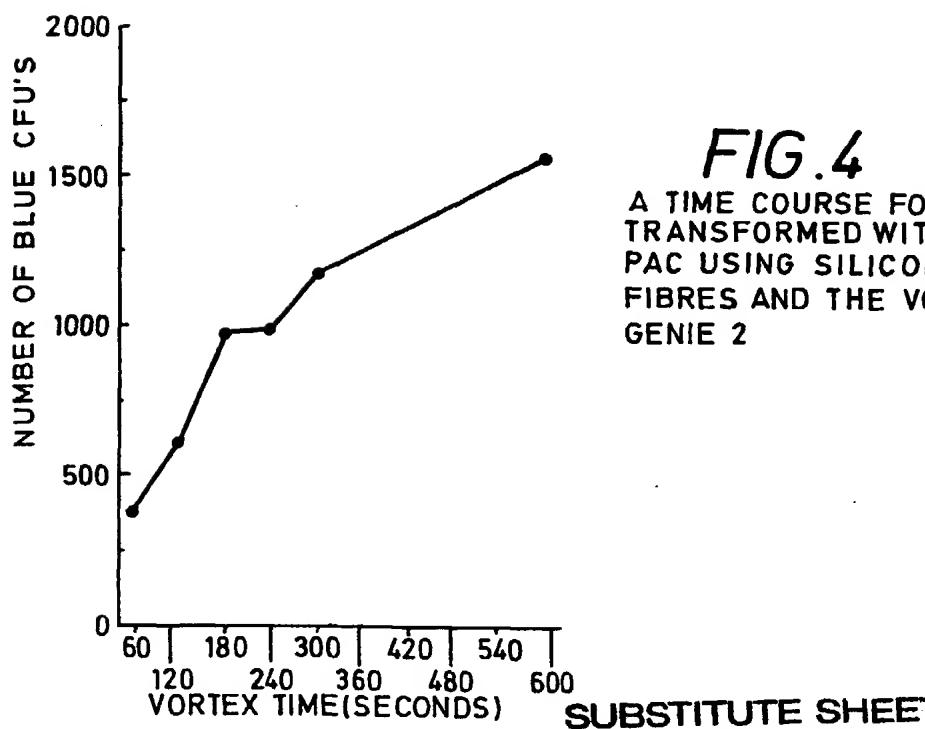
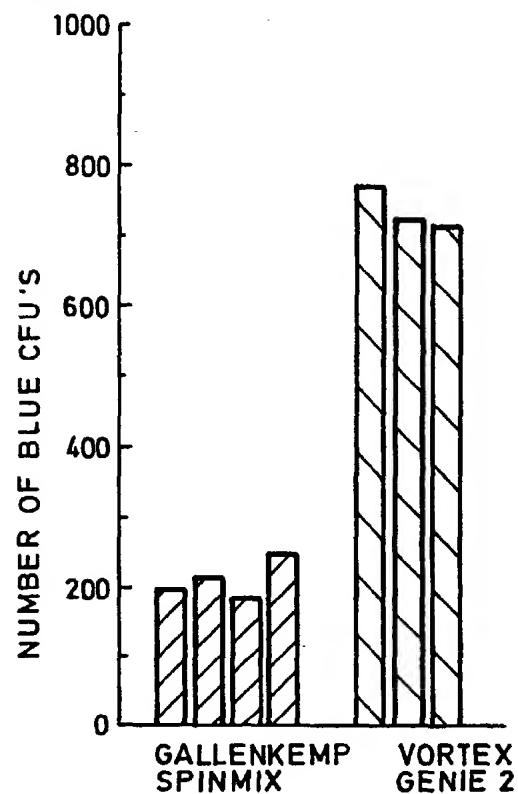
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**FIG. 2**  
**COMPARISON OF MIXING MATERIALS ON P35S-PAC  
 EXPRESSION IN AS51-C6 SUSPENSION CELLS.**



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**FIG.3** 3 / 10  
DNA TRANSFORMATION OF BMS WITH p35S-PAC  
COMPARING THE GALLENKAMP SPINMIX AND THE  
VORTEX GENIE 2



**FIG.4**  
A TIME COURSE FOR BMS  
TRANSFORMED WITH p35S-  
PAC USING SILICON CARBIDE  
FIBRES AND THE VORTEX  
GENIE 2

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4 / 10 FIG. 5

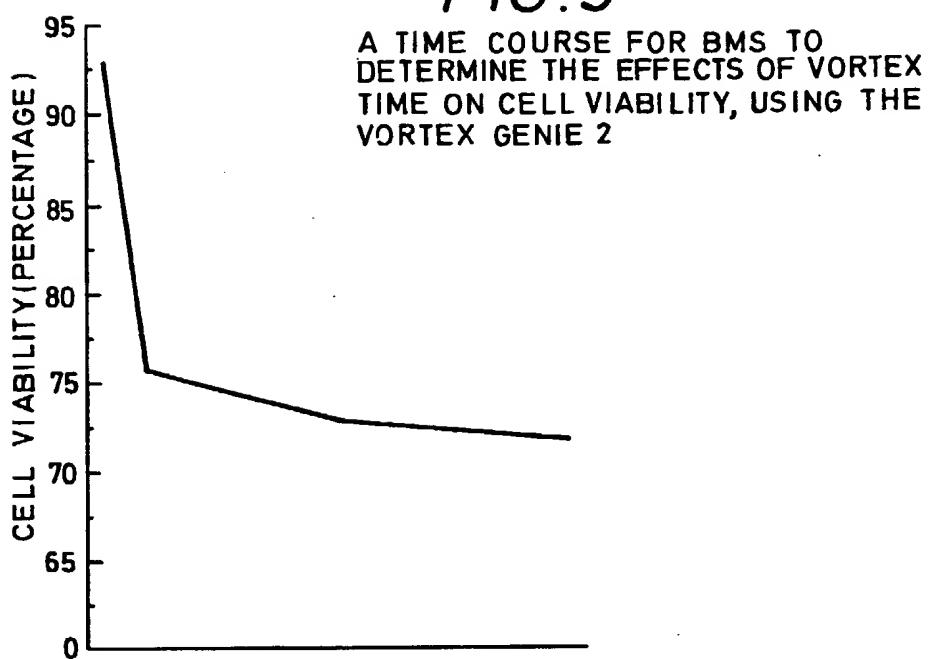
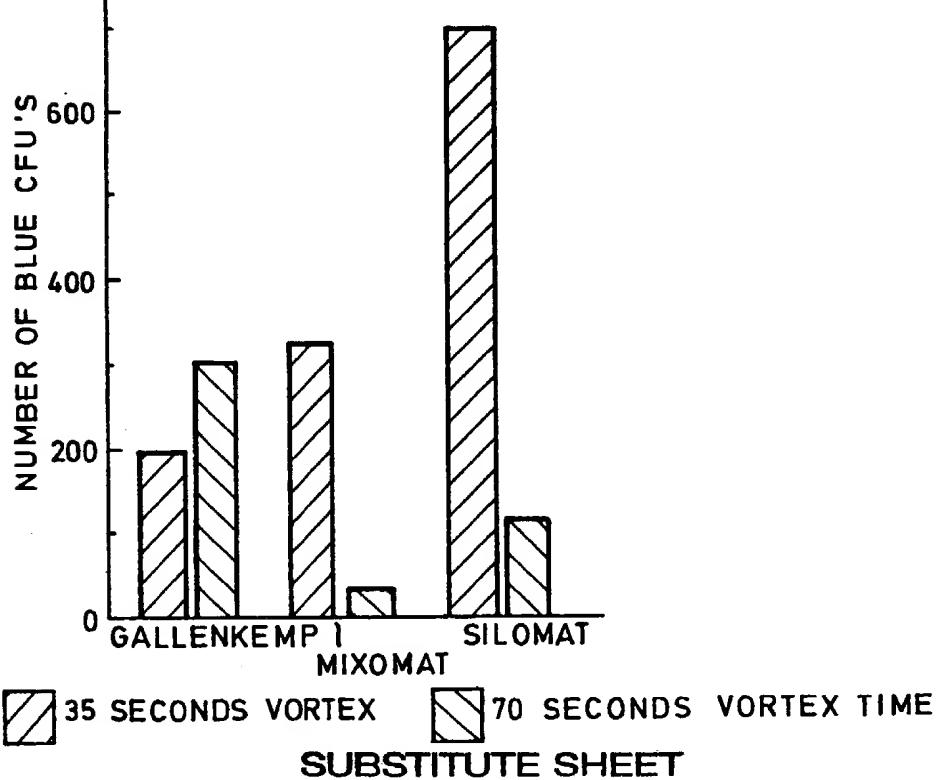
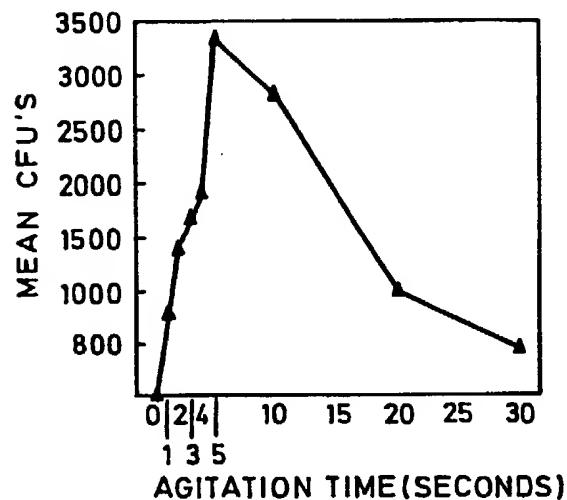


FIG. 6 DNA TRANSFORMATION OF BMS, COMPARING THE GALENKEMP SPINMIX AND TWO DENTAL AMALGAM MIXERS



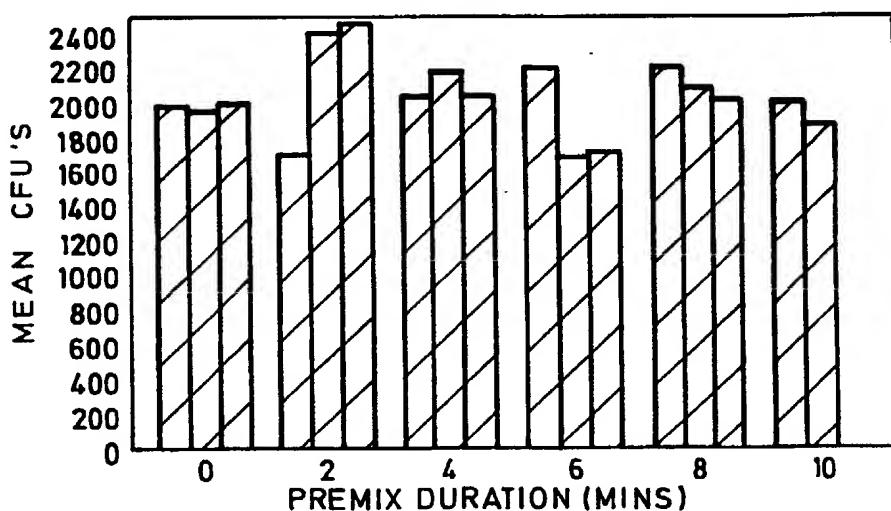
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**FIG. 7**  
EFFECTS OF MIXOMAT TREATMENT TIME ON  
TRANSIENT GUS EXPRESSION IN BMS



**FIG. 8**  
THE EFFECT OF PRE-MIXING OF WHISKERS WITH DNA ON GUS  
EXPRESSION IN A5D1-C6

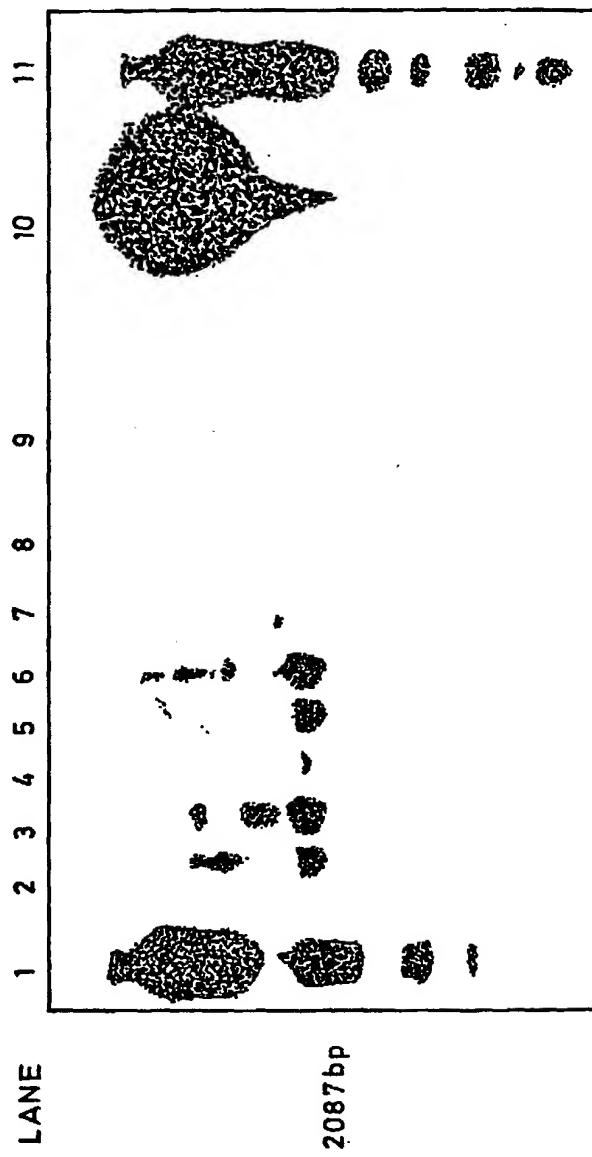
PREMIX DURATION EFFECT ON TRANSIENT EXPRESSION  
OF pMRP8 IN SiC FIBRE TREATED A5D1 C6



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**FIG. 9**  
SOUTHERN BLOTH OF FIVE BIALAPHOS RESISTANT GUS EXPRESSING CALLUS LINES

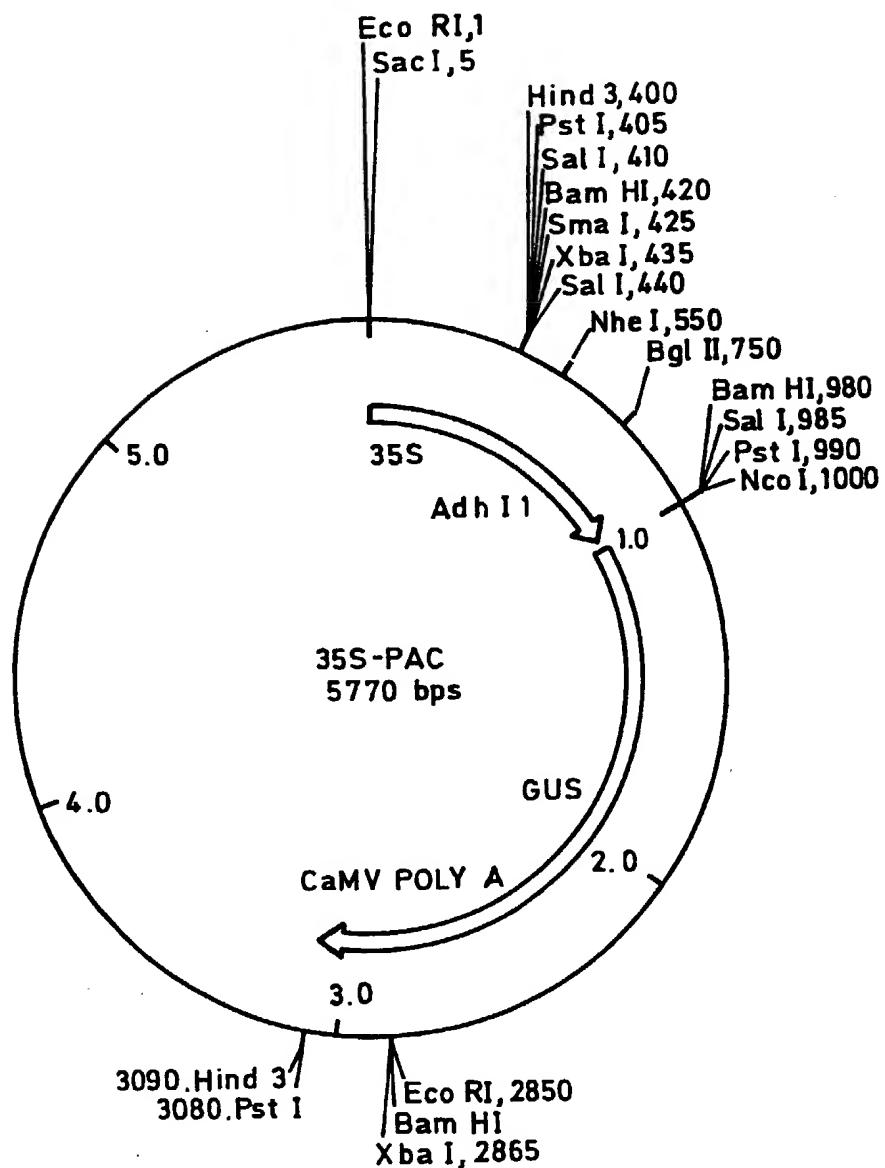


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FIG.10(1/4)



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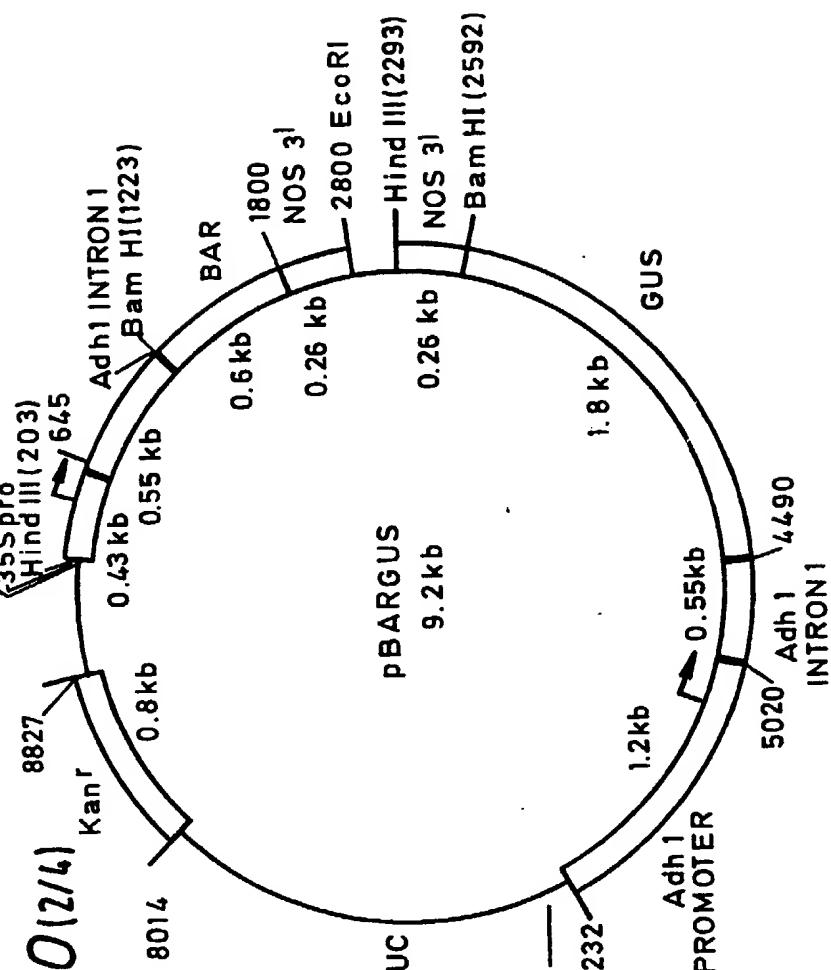
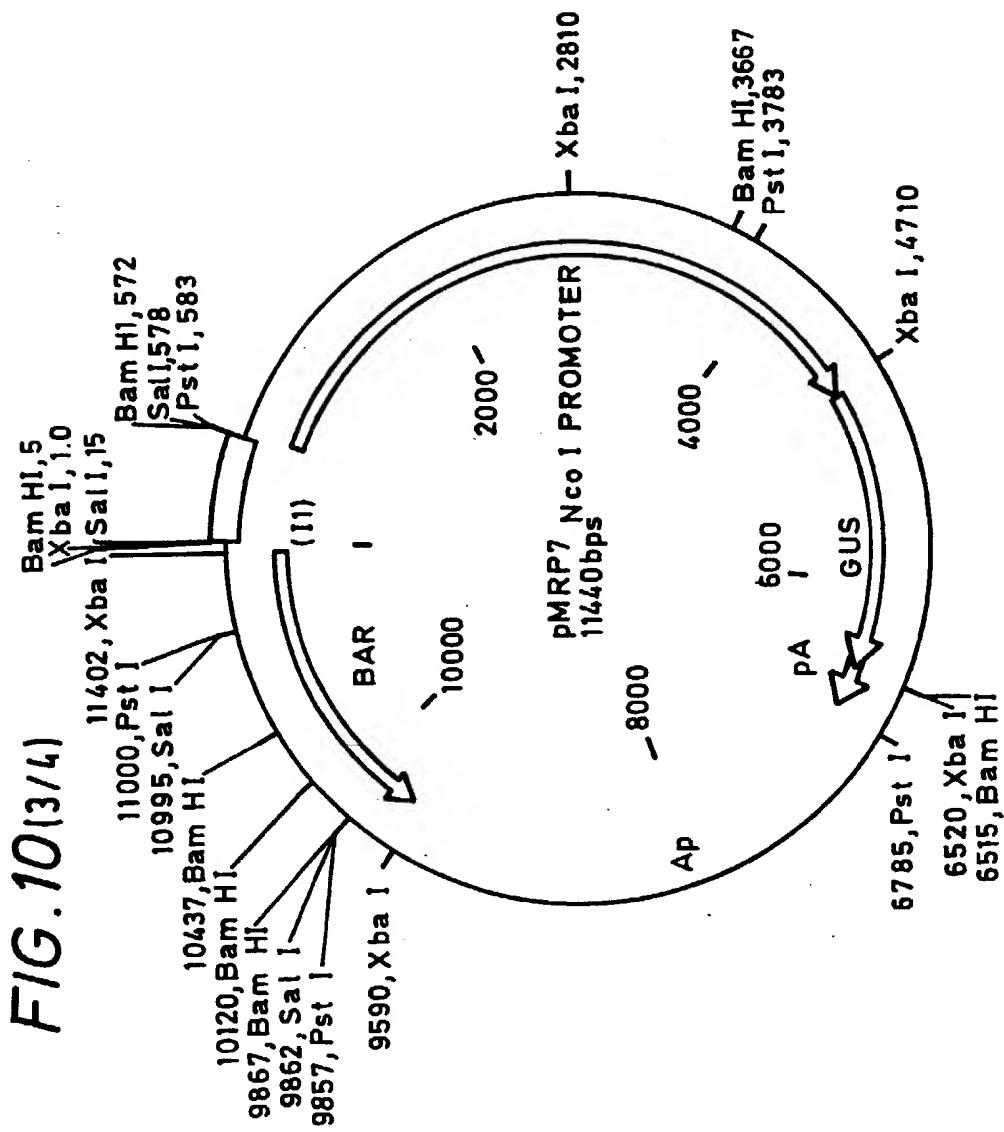


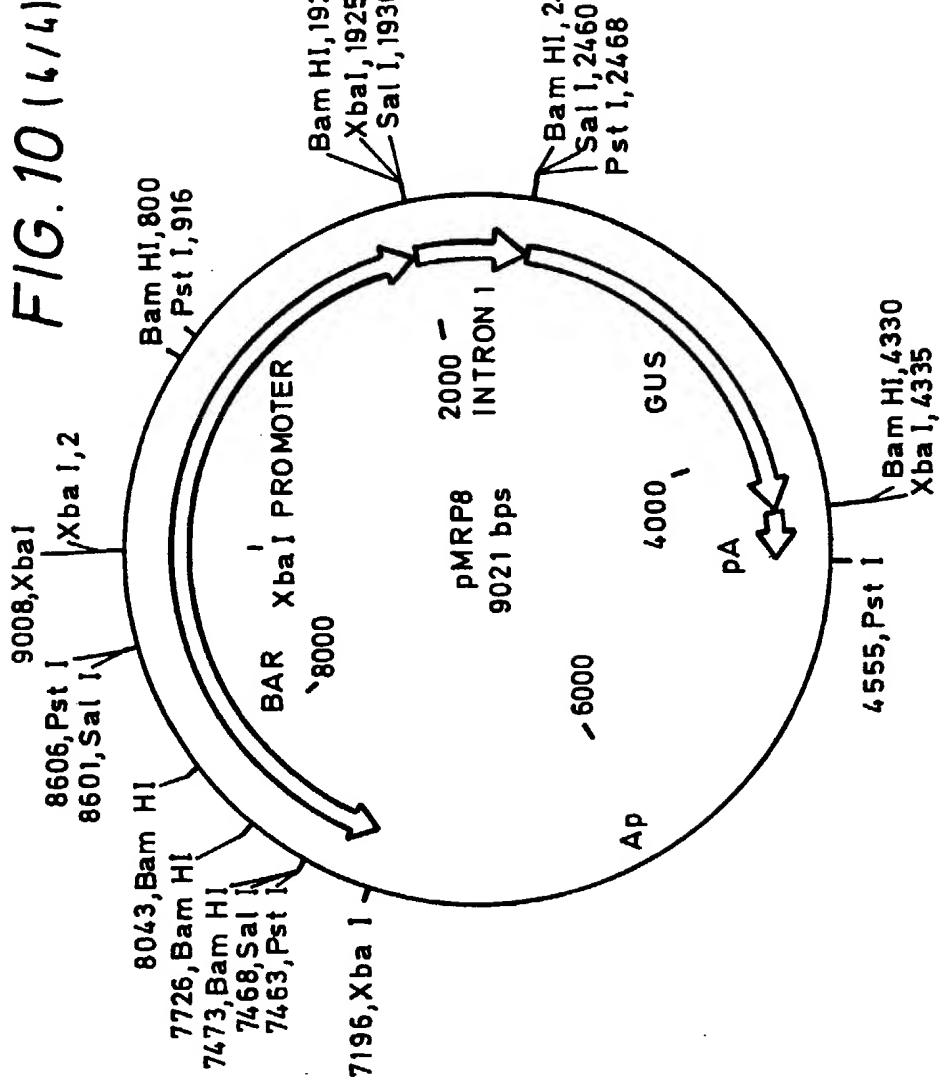
FIG. 10 (2/4)

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## INTERNATIONAL SEARCH REPORT

Int. Application No  
PCT/GB 93/01162

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 5 C12N15/82 C12N15/87

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 C12N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
|------------|--|-----------------------|
| X          | <p>PLANT CELL REPORTS<br/>vol. 9, November 1990<br/>pages 415 - 418<br/>KAEPPLER, H.F., ET AL. 'Silicon carbide<br/>fiber-mediated DNA delivery into plant<br/>cells'<br/>cited in the application<br/>see the whole document</p> <p>-----</p> | 1-6, 10,<br>11        |
| X          | <p>DATABASE WPI<br/>Section Ch, Week 9045,<br/>Derwent Publications Ltd., London, GB;<br/>Class B04, AN 90-341996<br/>&amp; US,A,7 472 538 (AGRIC RES SERVICE) 16<br/>October 1990<br/>see abstract</p> <p>-----</p> <p>-/-</p>                | 1-6                   |



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

\* Special categories of cited documents :

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1

Date of the actual completion of the international search

28 January 1994

Date of mailing of the international search report

22-02- 1994

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## INTERNATIONAL SEARCH REPORT

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No. |
|----------|---|-----------------------|
| X        | THOER. APPL. GENET.<br>vol. 84 , 1992<br>pages 560 - 566<br>KLAEPFER, H.F., ET AL. 'Silicon carbide<br>fiber-mediated stable transformation of<br>plant cells'<br>cited in the application<br>see the whole document<br>---   | 1-6,8,9 >             |
| A        | EP,A,0 331 083 (SCHWEIZERISCHE<br>EIDGENOSSENSHAFT ETH) 6 September 1989<br>see claim 19<br>---   | 7                     |
| A        | THE PLANT CELL.<br>vol. 2, no. 7 , July 1990 , ROCKVILLE, MD,<br>USA.<br>pages 603 - 618<br>GORDON-KAMM, W.J., ET AL. 'Transformation<br>of maize cells and regeneration of fertile<br>transgenic plants'<br>see the whole document<br>---  | 9-11                  |
| A        | THE PLANT CELL.<br>vol. 4, no. 12 , December 1992 ,<br>ROCKVILLE, MD, USA.<br>pages 1495 - 1505<br>D'HALLUIN, K., ET AL. 'Transgenic maize<br>plants by tissue electroporation'<br>see the whole document<br>---  | 12,13                 |
| A        | CHEMICAL ABSTRACTS, vol. 104, no. 23,<br>1986, Columbus, Ohio, US;<br>abstract no. 201545,<br>PASTENAK, T.P., ET AL. 'Genetic<br>transformation of higher plant cells by<br>DNA microinjections'<br>see abstract<br>& IZV. AKAD. NAUK SSSR, SER BIOL.<br>no. 2 , 1986<br>pages 314 - 316<br>--- | 14                    |
| A        | WO,A,92 12250 (DEKALB) 23 July 1992<br>see examples 4,10<br>-----   | 7,14                  |

**INTERNATIONAL SEARCH REPORT**  
*Information on patent family members*

Int'l Application No  
**PCT/GB 93/01162**

| Patent document cited in search report | Publication date | Patent family member(s) |         | Publication date |
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| WO-A-9212250                           | 23-07-92         | AU-A-                   | 9176991 | 17-08-92         |
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